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(PH-91)

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THE MEASUREMENT OF PHOSPHOR GRAIN AND ELECTRICAL NOISE COMPONENTS IN THE SIGNALS FROM A FLYING-SPOT TELECINE

Summary

Measurements are frequently made of the signal-to-noise ratios of signals from flying-spot telecines. The results do not indicate whether the measured noise is predominantly photomultiplier noise or due to the static pattern of the phosphor grain of the scanning tube. The methods described attempt to distinguish between noise and grain in order that a more complete measure of the cathode-ray tube performance can be made.

1. Introduction

The random fluctuation noise component of a flying-spot telecine output signal is almost entirely generated by the photomultiplier, whose noise output varies as the square root of the input illumination. The noise distribution over the grey scale range of signal amplitude will therefore not be uniform.

In measuring the signal-to-noise ratio of a telecine, the signal amplitude is clearly important and therefore a standard approach is necessary in order that results may be compared. The method normally adopted consists of measuring, by means of a noise meter,* the noise in the gamma corrected signal for a photomultiplier signal equal to ten per cent of white level. This signal is achieved by first placing in the telecine light path a neutral density filter (ND = 0·3) and setting the telecine up for white level output then adding a further filter (ND = 1·0) in the light path. It has been pointed out by C.B.B. Wood that small variations in gamma from one telecine to another would introduce a minimum of change in the noise voltage at this level, and therefore the results of measurements on several telecine machines may be compared.

This method, whilst sufficient for checking telecine performance for maintenance purposes, may lead to inaccurate conclusions if used to indicate absolute performance.

With the recent improvements in cathode-ray tube phosphor efficiency, the noise produced by the photomultiplier may be of similar magnitude to the random variation of brightness of the cathode ray tube due to the phosphor ganularity as the scanning spot moves across the screen.

The measured noise at the telecine output will therefore not be wholly random fluctuation noise due to the photomultiplier but the sum of the 'granularity noise' and the electrical noise. It is important to distinguish between these components as their visibility in the television picture is of a different nature and also so that manufacturers may be informed of the correct characteristics of cathode-ray and photomultiplier tubes in order to assist with the development of improved types.

Means will therefore be described by which the relative magnitudes of the noise and grain components of the telecine video signal may be found from signal-to-noise ratio measurements.

2. An alternative method of noise measurement

When measuring the signal-to-noise ratio of a colour telecine by the established method it is important that the neutral density filter should attenuate the red, green and blue light equally in order to produce the correct photomultiplier signals. In colour telecines it is common to observe differences in the attenuation with a given filter and this gives rise to incorrect noise currents from the photomultipliers. Due to the incorrect signal levels, the gamma correctors then apply a different amount of amplification in each channel and as a result the measurements will not accurately represent the noise performance at the photomultiplier signal level of ten percent white level.

In order to overcome some of these problems the signal could be measured before gamma correction under open gate, white level conditions. This would eliminate the need for a neutral density filter and the gamma corrector.

Unfortunately this is not entirely satisfactory since, under these conditions, the ratio of signal to random-fluctuation noise will be at its greatest and the 'coherent' noise component due to phosphor grain may predominate in the measurement. The suggestion is made from time to time that the effect of phosphor grain can be eliminated by defocusing the flying-spot tube. If, as is often the case, the

* for example, the BBC noise meter type ME1/502.

tube is operated with the phosphor in a state of saturation, the light output increases considerably upon defocusing, and the electrical circuits of the telecine may become overloaded. Where the phosphor is not fully saturated the effect will be less pronounced and meaningful measurements may be made. The procedure for each channel is then as follows:

(1) Set the tube beam-current to normal

(2) Set the photomultiplier gain for white-level output

(3) Defocus the tube

(4) Measure the signal-to-noise ratio of the signal, prior to gamma correction, using a noise meter

(5) Re-adjust the photomultiplier gain to restore the signal magnitude to white level

(6) Measure the signal-to-noise ratio again, as before

(7) Average the two measurements (in dB) of signal-to-noise ratio. This method gives the true signal-to-noise ratio obtained at white level.

2.1. Proof

The noise meter measures r.m.s. noise and is calibrated in terms of the ratio (in dB) to a standard signal level (white level). If the level of the linear signal from the p.e.c. changes from white level (V) to (qV) when defocused then the noise will be increased by $\sqrt{q}$ (since the r.m.s. noise voltage is proportional to the square root of the signal voltage).

Let the noise associated with white level signal, the tube being focused, be n_0

Let the noise measured with the tube defocused but gain unchanged, be n_1

Let the noise measured with the tube defocused but gain readjusted to give white level signal, be n_2

then

$$\log n_1 = \log n_0 + \tfrac{1}{2} \log q \text{ (light increased by factor q)} \quad (1)$$

$$\log n_2 = \log n_1 - \log q \text{ (gain reduced by factor q)} \quad (2)$$

$$\text{From (1) } \log n_0 = \log n_1 - \tfrac{1}{2} \log q$$

$$\text{From (2) } \log q = \log n_1 - \log n_2$$

$$\text{Therefore } \log n_0 = \log n_1 - \tfrac{1}{2} (\log n_1 - \log n_2) =$$

$$= \frac{\log n_1 + \log n_2}{2}$$

As an alternative to this method the beam current may be reduced after defocusing to restore the signal to the previous value of white level and the signal-to-noise ratio may then be measured directly.

Measurements made whilst the beam is defocused have not proved to be reliable since severe defocusing is sometimes required to remove the effect of phosphor grain and the scan size varies, causing in the case of a twin-lens telecine, flicker effects which may be measured together with the noise. The next section of this report describes a method of measuring noise and grain which is not dependent upon changing the tube operating conditions.

3. A method for separating random fluctuation noise and phosphor grain modulation

In order to separate the random noise and cathode-ray tube phosphor grain component the non-linear relationship between the light input and noise output of a photomultiplier may again be used.

Consider first the linear signal at white level. This signal contains a component due to the modulation of the signal by phosphor grain (G) and a component due to random fluctuation noise from the photomultiplier (N). These two signals add together statistically to give the measured noise component as shown below:

$$\text{Measured noise r.m.s. voltage } (a) = \sqrt{G^2 + N^2} \quad (3)$$

if a neutral density filter is introduced in the gate which reduces the white level signal (V) to (xV) then the r.m.s. noise measured will be given by:

$$b = \sqrt{x^2 G^2 + x N^2} \quad (4)$$

By measuring noise at two levels, peak white and at some much smaller signal level (xV) both the phosphor grain (G) and the photomultiplier noise (N) may be determined using Equations (3) and (4).

These equations give rise to the following expression for random fluctuation noise (N) and cathode ray tube phosphor grain (G).

$$N = \sqrt{\frac{b^2 - a^2 x^2}{x - x^2}} \quad (5)$$

$$G = \sqrt{\frac{a^2 x - b^2}{x - x^2}} \quad (6)$$

where a, b, N and G represent r.m.s. voltages. The noise meter readings in decibels below white level must therefore be converted to r.m.s. noise voltages a and b and then the final noise and grain voltages obtained by calculation.

* Note that the coefficient of G^2 is x^2 but the coefficient of N^2 is x. The grain varies linearly with the attenuation caused by the neutral density filter but the noise remains proportional to the square root of the signal.

From the expressions for noise and grain it can be seen that the second measurement of signal-to-noise ratio (at xV) must be made at such a level that x is small otherwise, due to the denominators in the expressions, the results of the calculation will be inaccurate.

The method also becomes inaccurate if the noise component and grain component are substantially different in amplitude. The smaller of the two will not be determined accurately and the average of several measurements may have to be taken. It is assumed that other noise components such as head amplifier noise which are included in the measurements are sufficiently small to have no effect.

4. Estimation of possible errors

Errors may occur in the measurement of noise and of signal amplitude. An expression for the error may be derived by differentiation of the grain and noise equations. The calculations are shown in Appendix 1.

If an assumed error of noise meter reading is taken to be ±0·1 dB and the error of reading signal amplitude is taken as ±1%, the maximum error may be calculated. Some typical measurements, together with the calculated results are shown below.

5. Conclusions

The method described for separating the photomultiplier noise and phosphor grain components in the output of a flying-spot telecine enables more accurate and independent measurements to be made of the performance of photomultipliers and flying-spot tubes. It is now possible to determine the separate contributions of random fluctuation noise and phosphor grain with sufficient accuracy to make judgements as to whether increase of light output or reduction of phosphor grain is the more pressing requirement in any development work on cathode-ray tubes. It is also possible to measure the contribution of random fluctuation noise made by different types of photomultipliers.

Tube 1 Grain > Noise	R	G	B
Measured open-gate signal-to-noise ratio (dB)	37·1	39·4	34·1
Measured signal-to-noise ratio with N.D. filter present (dB)	47·2	50·5	46·0
Signal level with N.D. filter present (x%)	18·0	18·0	15·0
Calculated noise component (dB)	40·6	44·5	38·9
Possible error due to assumed measurement error (dB)	0·6	0·7	0·7
Calculated grain component (dB)	39·6	41·0	35·8
Possible error due to assumed measurement error (dB)	0·5	0·4	0·4

Tube 2 Grain < Noise	R	G	B
Measured open-gate signal-to-noise ratio (dB)	27·9	31·4	34·2
Measured signal-to-noise ratio with N.D. filter present (dB)	35·5	39·4	42·9
Signal level with N.D. filter present (x%)	20·4	20·1	16·0
Calculated noise component (dB)	28·8	32·8	35·1
Possible error due to assumed measurement error (dB)	0·4	0·5	0·5
Calculated grain component (dB)	35·2	36·9	41·5
Possible error due to assumed measurement error (dB)	2·0	1·3	2·1

APPENDIX 1
Estimation of Errors

$$\text{Noise voltage } (N) = \sqrt{\frac{b^2 - a^2x^2}{x - x^2}} \qquad (5)$$

$$\text{Grain } (G) \text{ (equivalent r.m.s. voltage)} = \sqrt{\frac{a^2x - b^2}{x - x^2}} \qquad (6)$$

Noise Equation

$$N^2(x - x^2) = b^2 - a^2x^2 \qquad \text{from (5)}$$

$$\therefore 2N\delta N(x - x^2) + N^2(1 - 2x)\delta x = 2b\delta b - 2ax^2\delta a - 2xa^2\delta x$$

$$\therefore \quad \delta N = \frac{N^2(2x - 1)\delta x + 2b\delta b - 2ax^2\delta a - 2xa^2\delta x}{2N(x - x^2)}$$

$$= \frac{2b\delta b - 2ax^2\delta a - N^2\left(1 + 2x\left(\frac{a^2}{N^2} - 1\right)\right)\delta x}{2N(x - x^2)}$$

Values of δa and δb are derived as follows from noise meter readings.

Let A dB be the reading of signal-to-noise ratio under open gate conditions with a signal level of 0·7 volts.

Let B dB be the reading of signal-to-noise ratio with the neutral density filter present.

Then $A(\text{dB}) = -20 \log_{10} \frac{a}{0{\cdot}7}$ and $B(\text{dB}) = -20 \log_{10} \frac{b}{0{\cdot}7}$

$$\therefore \delta A = \frac{-20p\delta a}{a} \text{ and } \delta B = \frac{-20p\delta b}{b}$$

where $p = \log_{10} e$

$$\therefore \delta a = \frac{-a\delta A}{20p} \text{ and } \delta b = \frac{-b\delta B}{20p}$$

Assuming errors of ±0·1 dB in noise meter readings and ±1% in the amplitude of x then the maximum error may be found.

This will occur when the numerator terms of Equation (7) are all of the same sign:

from (3) $a^2 \geqslant N^2$

$$\therefore \frac{a^2}{N^2} - 1 \geqslant 0$$

$$x > 0$$

$$N^2 > 0$$

$$\therefore N^2\left(1 + 2x\left(\frac{a^2}{N^2} - 1\right)\right) > 0$$

$$\therefore \delta N_{max} = \pm\left[\frac{2b\delta b - 2ax^2(-\delta a) - N^2\left(1 + 2x\left(\frac{a^2}{N^2} - 1\right)\right)(-\delta x)}{2N(x - x^2)}\right]$$

Substituting values of δa, δb and δx

Maximum error $\delta N =$

$$= \pm\left[\frac{\frac{0{\cdot}2b^2}{20p} + \frac{0{\cdot}2a^2x^2}{20p} + 0{\cdot}01N^2\left(1 + 2x\left(\frac{a^2}{N^2} - 1\right)\right)}{2N(x - x^2)}\right]$$

$$= \pm 0{\cdot}01\left[\frac{\frac{b^2}{p} + \frac{a^2x^2}{p} + N^2\left(1 + 2x\left(\frac{a^2}{N^2} - 1\right)\right)}{2N(x - x^2)}\right]$$

Similarly, for the error in estimating the phosphor grain:

$$\delta G = \frac{G^2(2x - 1)\delta x + 2ax\delta a + a^2\delta x - 2b\delta b}{2G(x - x^2)}$$

$$= \frac{2ax\delta a - 2b\delta b + G^2\left(2x + \left(\frac{a^2}{G^2} - 1\right)\right)\delta x}{2G(x - x^2)}$$

from (3) $a^2 \geqslant G^2$ $\therefore$ for the maximum error δa and δx are positive and δb is negative. Substituting values of δa, δb and δx then,

$$\delta G_{max} = \pm 0{\cdot}01\left[\frac{\frac{a^2x}{p} + \frac{b^2}{p} + G^2\left(2x + \left(\frac{a^2}{G^2} - 1\right)\right)}{2G(x - x^2)}\right]$$